CLAIMS

1. A method of providing closed-loop control of power flowing into and out of an electrical energy storage system, comprising the steps of:

determining a charge power limit comprising a maximum charge power during each of a plurality of control loops;

determining a discharge power limit comprising a maximum discharge power during each of the plurality of control loops;

comparing the charge power limit and the discharge power limit during each of the plurality of control loops; and

providing a charge power limit output and a discharge power limit output for use in a subsequent control loop which are based upon the charge power limit and the discharge power limit, wherein the charge power limit output and discharge power limit output are equal to the discharge power limit and charge power limit, respectively, when the discharge power limit is greater than the charge power limit; and wherein the charge power limit output and discharge power limit output are selected from the group consisting of the charge power limit, the discharge power limit and zero when the discharge power limit is less than or equal to the charge power limit.

2. The method of claim 1, wherein the step of determining a charge power limit, comprises the further steps of:

determining an overvoltage-based power rate limit during each of the plurality of control loops;

determining a minimum charge power limit and a maximum charge power limit during each of the plurality of control loops; and

performing a limited integration of the overvoltage-based power rate limit, minimum charge power limit and maximum charge power limit to determine the maximum charge power.

3. The method of claim 2, wherein the step of determining the overvoltage-based power rate limit comprises the further steps of:

determining a temperature and a voltage of the ESS;

determining an overvoltage value for the battery using a warning track approach as a function of the battery temperature and voltage, wherein the warning track approach avoids the selection of an overvoltage value for use in the control loop that could result in an overvoltage condition in the ESS;

determining a proportional overvoltage gain (G_{OP}) and a derivative overvoltage gain (G_{OD}); and

calculating an overvoltage-based power rate limit as a function of the overvoltage value and the battery voltage using a proportional derivative controller.

4. The method of claim 3, wherein the step of determining an overvoltage value using the warning track approach, comprises the further steps of:

determining a base overvoltage value for the ESS as a function of the temperature of the ESS;

adding a first overvoltage offset to the base overvoltage value to establish a warning track overvoltage value as a function of the temperature of the ESS;

adding a second overvoltage offset from the warning track overvoltage value to establish a warning track overvoltage threshold value of the ESS; and

determining an overvoltage value as a function of time, temperature and ESS voltage.

5. The method of claim 4, wherein the base overvoltage value is selected from a look-up table as a function of the ESS temperature, the first overvoltage offset comprises a scalar voltage value.

6. The method of claim 5, wherein the step of determining the overvoltage value comprises setting the overvoltage reference value equal to the overvoltage warning track threshold when the battery voltage is less than the overvoltage warning track threshold, increasing the overvoltage reference value monotonically at a predetermined overvoltage reference rate from the overvoltage threshold value to the base overvoltage value when the ESS voltage is greater than or equal to the overvoltage warning track threshold.

7. The method of claim 6, wherein the predetermined overvoltage reference value is selected from a look-up table as a function of the ESS temperature.

8. The method of claim 3, wherein the step of calculating the overvoltage-based power rate limit comprises the further steps of:

determining an overvoltage reference error between the overvoltage reference value and ESS voltage;

multiplying the overvoltage reference error by G_{OP} and adding it to the derivative of the voltage reference error multiplied by the G_{OD} to develop an overvoltage-based power rate limit.

9. The method of claim 2, wherein the step of determining a minimum charge power limit and a maximum charge power limit comprises selecting each of the minimum charge power limit and a maximum charge power limit from a respective look-up table.

10. The method of claim 9, wherein the step of performing the limited integration comprises a comparison of parametric ESS limits from the group consisting of ESS temperature, SOC and amp-hour per hour throughput.

11. The method of claim 1, wherein the step of determining a discharge power limit, comprises the further steps of:

determining an undervoltage-based power rate limit during each of the plurality of control loops;

determining a minimum discharge power limit and a maximum discharge power limit during each of the plurality of control loops; and

performing a limited integration of the undervoltage-based power rate limit, minimum discharge power limit and maximum discharge power limit to determine the maximum discharge power.

12. The method of claim 11, wherein the step of determining the undervoltage-based power rate limit comprises the further steps of :

determining a temperature and a voltage of the ESS;

determining an undervoltage value for the battery using a warning track approach as a function of the battery temperature and voltage, wherein the warning track approach avoids the selection of an undervoltage value for use in the control loop that could result in an undervoltage condition in the battery;

determining a proportional undervoltage gain (G_{UP}) and a derivative undervoltage gain (G_{UD}); and

calculating an undervoltage-based power rate limit as a function of the undervoltage value and the battery voltage using a proportional derivative controller.

13. The method of claim 12, wherein the step of determining an undervoltage value using the warning track approach, comprises the further steps of:

determining a base undervoltage value for the ESS as a function of the temperature of the ESS;

adding a first undervoltage offset to the base overvoltage value to establish a warning track undervoltage value as a function of the temperature of the ESS;

adding a second undervoltage offset from the warning track undervoltage value to establish a warning track undervoltage threshold value ; and

determining an undervoltage value as a function of time, temperature and battery voltage.

14. The method of claim 13, wherein the base undervoltage value is selected from a look-up table as a function of the ESS temperature, the first undervoltage offset comprises a scalar voltage value and the second undervoltage offset comprises a scalar voltage value.

15. The method of claim 14, wherein the step of determining the undervoltage value comprises setting the undervoltage reference value equal to the undervoltage warning track threshold when the battery voltage is less than the undervoltage warning track threshold, increasing the undervoltage reference value monotonically at a predetermined undervoltage reference rate from the undervoltage threshold value to the base undervoltage value when the battery voltage is less than or equal to the undervoltage warning track threshold.

16. The method of claim 15, wherein the predetermined undervoltage reference rate is selected from a look-up table as a function of the ESS temperature.

17. The method of claim 12, wherein the step of calculating the undervoltage-based power rate limit comprises the further steps of:

determining an undervoltage reference error between the undervoltage reference value and battery voltage;

multiplying the undervoltage reference error by G_{UP} and adding it to the derivative of the voltage reference error multiplied by the G_{UD} to develop an undervoltage-based power rate limit.

18. The method of claim 11, wherein the step of determining a minimum discharge power limit and a maximum discharge power limit

comprises selecting each of the minimum discharge power limit and a maximum discharge power limit from a respective look-up table.

19. The method of claim 18, wherein the step of performing the limited integration comprises a comparison of parametric ESS limits from the group consisting of ESS temperature, SOC and amp-hour per hour throughput.

20. A method of providing closed-loop control of power flowing into and out of an energy storage system of a hybrid electric vehicle, comprising the steps of:

determining a charge power limit comprising a maximum charge power during each of a plurality of control loops by determining an overvoltage-based power rate limit during each of the plurality of control loops, determining a minimum charge power limit and a maximum charge power limit during each of the plurality of control loops, and performing a limited integration of the overvoltage-based power rate limit, minimum charge power limit and maximum charge power limit to determine the maximum charge power.;

determining a discharge power limit comprising a maximum discharge power during each of the plurality of control loops by determining an undervoltage-based power rate limit during each of the plurality of control loops, determining a minimum discharge power limit and a maximum discharge power limit during each of the plurality of control loops, and performing a limited integration of the undervoltage-based power rate limit, minimum discharge power limit and maximum discharge power limit to determine the maximum discharge power.

comparing the discharge power limit and the charge power limit during each of the plurality of control loops; and

providing a charge power limit output and a discharge power limit output for use in a subsequent control loop which are based upon the charge power limit and the discharge power limit, wherein the charge power limit output and discharge power limit output are equal to the

discharge power limit and charge power limit, respectively, when the discharge power limit is greater than the charge power limit; and wherein the charge power limit output and discharge power limit output are selected from the group consisting of the charge power limit, the discharge power limit and zero when the discharge power limit is less than or equal to the charge power limit.

21. The method of claim 20, wherein the step of determining an overvoltage-based power rate limit, comprises the further steps of:

determining the temperature of the ESS

determining a base overvoltage value for the ESS as a function of the temperature of the ESS;;

subtracting an first overvoltage offset from the base overvoltage value to establish a warning track overvoltage value as a function of the temperature of the ESS;

subtracting an second overvoltage offset from the warning track overvoltage value to establish a warning track overvoltage threshold value as a function of the temperature of the ESS;

determining a battery voltage of the ESS as a function of time;

calculating an overvoltage reference value from the warning track overvoltage value as a function of time and the battery voltage and an overvoltage reference error between the overvoltage reference value and battery voltage using a proportional derivative controller having a proportional overvoltage gain (G_{OP}) and a derivative overvoltage gain (G_{OD}); and

multiplying the overvoltage reference error by the G_{OP} and adding it to the derivative of the voltage reference error multiplied by the G_{OD} to develop an overvoltage-based power rate limit.

22. The method of claim 21, wherein the step of determining an undervoltage-based power rate limit, comprises the further steps of:

determining the temperature of the ESS

determining a base undervoltage value for the ESS as a function of the temperature of the ESS;;

adding a first undervoltage offset from the base undervoltage value to establish an warning track undervoltage value as a function of the temperature of the ESS;

adding a second undervoltage offset from the warning track undervoltage value to establish a warning track undervoltage threshold value as a function of the temperature of the ESS;

determining the battery voltage of the ESS as a function of time during the control loop

calculating an undervoltage reference value from the warning track undervoltage value as a function of time and the battery voltage and a undervoltage reference error between the undervoltage reference value and battery voltage using a proportional derivative controller having a proportional undervoltage gain (G_{UP}) and a derivative undervoltage gain (G_{UD}); and

multiplying the undervoltage reference error by the G_{UP} and adding it to the derivative of the undervoltage reference error multiplied by the G_{UD} to develop an undervoltage-based power rate limit.

23. The method of claim 22, wherein the step of determining a minimum charge power limit and a maximum charge power limit comprises selecting each of the minimum charge power limit and a maximum charge power limit from a respective look-up table, and wherein the step of determining a minimum discharge power limit and a maximum discharge power limit comprises selecting each of the minimum discharge power limit and a maximum discharge power limit from a respective look-up table.

24. The method claim23, wherein the step of performing the limited integration comprises a comparison of parametric ESS limits from the group consisting of ESS temperature, SOC and amp-hour per hour throughput..

25. The method of claim 20, wherein when the discharge power limit is greater than the charge power limit; the maxim discharge power output is set equal to the maximum discharge power value and the maximum charge power is set equal to zero when both the maximum charge power and maximum discharge power are greater than zero; the maxim charge power output is set equal to the maximum charge power value and the maximum discharge power is set equal to zero when both the maximum charge power and maximum discharge power are less than zero; and the maxim charge power output and maximum discharge power output are set equal to zero when the maximum charge power is greater than zero and the maximum discharge power is less than zero.